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VIBRATION CHARACTERISTICS OF A LASER HETERODYNE SPECTROMETER TUNABLE DIODE LASER SYSTEM USING A MECHANICAL COOLER PLATFORM

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SUMMARY

An experiment test was performed on the newly designed Laser Heterodyne Spectrometer (LHS) system with emphasis on determining the extent of motion isolation of the Tunable Diode Laser (TDL). Various configurations involving different isolators were studied as well as different operating conditions, i.e., compressor and vacuum pumps on or off. The results are presented in the form of power-spectral-density analyses, rms and peak displacement values, and amplitude histogram for various configurations. The redesign of the LHS system using Isolation Bellows together with vertical rubber isolators at the center of gravity plane provided for an adequate isolation of the TDL.

INTRODUCTION

The Langley Research Center is currently developing a highly sensitive instrument for remotely measuring the chemical elements of the atmosphere. The instrument is the Laser Heterodyne Spectrometer (LHS), which functions optically and is subject to very strict operating parameters, i.e., motion and temperature. Considerable experimental and analytical studies were performed on various configurations of the LHS concept to investigate the effectiveness of different designs for isolating the motion of the LHS. The critical component of the LHS system is the Tunable Diode Laser (TDL) which must operate under very stringent motion limitations. The criteria established for an acceptable motion of the TDL is less than 1 micron,

N81-25361 #

double amplitude. The LHS is being developed for an aircraft flight demonstration in 1982. This aircraft experiment will require the LHS to be mounted on a 121.92 x 213.36 cm by 20.32 cm thick honeycomb isolation table. Analysis of this system is underway and will be reported at a later date.

The purpose of this report is to present the results of an experimental test performed on the newly designed LHS Model 21 Cooler to determine the most effective isolators to minimize the motion of the TDL.

DESCRIPTION OF LHS MODEL 21 COOLER

In the original design of the LHS, the TDL was attached to the cooler housing and the motions of the TDL were similar to the motions of the cooler during operation, and were unacceptable (see figure 1). Four rubber isolators were located at the bottom of the cooler section, which isolated the LHS from housing. However, motion was transmitted from the cooler through the isolators to the housing and to the TDL suspension. Also, motion of the Cold Tip was transmitted through the Thermal Strap to the TDL. An analytical model of this design was studied earlier, to evaluate different types of isolators to minimize the response of the TDL. It should be noted, that in this paper, the experimental tests which were performed with different isolators were chosen from the above mentioned analysis.

In the newly designed LHS, the TDL is dynamically isolated from the cooler by means of two bellows, an Isolation Bellows and Reaction Bellows (see figure 2). In the new design, the four vertical isolators were located in the horizontal plane through the center gravity similar to the longitudinal isolators shown in figure 2. (Note, that the vertical isolators are shown at the bottom of the cooler section for clarity). The two longitudinal isolators that were used

in the analysis mentioned above, were incorporated in the new design on a trial basis.

EXPERIMENTAL TEST DESCRIPTION

Vibration tests were conducted on the LHS Model 21 Cooler mounted in a newly designed Cooler Mounting Bracket which dynamically isolated the TDL Housing Assembly (see figure 2). Four configurations of different rubber or neoprene isolation mounts were studied. All of the isolators were 2.54 cm (1 in.) in diameter, however, the thickness varied, including 2.54 cm, 1.905 cm (3/4 in.), and 1.27 cm (1/2 in.) thick and a hollow, spherical type. The new design incorporated four isolators in the vertical direction at the horizontal center of gravity plane, and two in the longitudinal direction in the same plane. During the operation of each configuration, several conditions were monitored, i.e., horizontal and vertical isolators in place, vertical isolators only, compressor on and off, vacuum pump on and off, etc.

The data were recorded at 19.05 cm (7.5 inches) per second on a 14 channel FM tape recorder having a carrier frequency of 13.5 KHZ. Six proximity probes were used to measure the response of the internal parts of the LHS system, and are shown in figures 3 and 4. Three directions were monitored on both the Cold tip and on the TDL. These probes measured linear response in mils, inches. Six accelerometers were used to measure the external response, i.e., accelerations of the mounting platform, the refrigerator, and various housing assemblies (see figure 5). In addition, two different 20°K flexible thermal straps were tested (see figure 2), namely, a braided copper strap, and a stranded copper strap. The initial run was performed with the braided strap, however, remaining tests were performed with the stranded strap.

RESULTS AND DISCUSSION

Experiment Test

The quantity of test data that was obtained from this study was substantial, but since the main focus of this investigation was the degree of amplitude attenuation at the TDL interface, most of the data presented pertains to the TDL. In addition, data from the Cold Tip are presented for comparison. It should be noted, that probe 4, longitudinal direction, was inoperative during most of the testing, therefore, data from probes 5 and 6, lateral and vertical direction, respectively, will be discussed mainly. The operation of probe 4 was limited to only the first few runs.

Frequency Analysis. - One of the initial tests to be performed, was to make a recording with everything off, in order to observe the instrumentation characteristics or background noise. The repeatable frequency that occurred with everything off, for probes 1-6, and accelerometer 1, was 60 Hz. This frequency was not present in the data for accelerometers 2 through 6. It should be noted that the 60 Hz was the predominant frequency for probes 4 through 6, (the TDL response). Figure 6 shows a PSD for probe 5, lateral direction, with the system shutdown which was typical for the three probes measuring the response of the TDL. Note the predominant frequency of 60 Hz.

During the testing of the Model 21 Cooler, various operating conditions were investigated. With all of the systems operating, i.e., compressor and vacuum pumps on, the predominant frequency that occurred was 3.4 Hz. This frequency is directly associated with the operation of the compressor for when the compressor was off, the frequency was eliminated, (see figure 7). Not only did the resonant frequency of 3.4 Hz disappear, but the overall response in this frequency range was about 4 magnitudes less than with the

compressor operating. In fact, when the compressor was off, the response of probe 5, lateral direction, as shown in the PSD plot in figure 7, is very similar to the response obtained when everything was off (figure 6). Note, that the response at 60 Hz is essentially at the same level as when everything was off, or about 10^{-8} power, (see figures 6 and 7).

Similar results were observed with probe 6, vertical direction, in that the 3.4 Hz response is eliminated, see figure 8. However, that similarity ends after about 10 Hz, when the response is not as attenuated as was with probe 5. The vibration characteristics of probe 6 with everything off are shown in figure 9. Note that the frequency peaks appear more pronounced for the probe 6, where the peak at 10 Hz is two orders of magnitude greater than that measured for probe 5 with everything off (figure 6). The response between 10 and 20 Hz is also greater for probe 6 (vertical direction) than for probe 5 (lateral direction). For a comparison purpose, the response of the Cold Tip in the vertical direction with everything off is shown in figure 10. Note the similarity of the two spectra, figures 9 and 10, between 10 and 60 Hz. However, the frequency response of the TDL is considerably less in magnitude.

Generally, the response of the TDL was less when the longitudinal isolators were not used as compared to when they were included. The effects of the longitudinal isolators can be observed in figure 11 where PSD plot of probes 5 and 6 are shown with and without the longitudinal isolator. For probe 5 (lateral direction) the effect of the longitudinal isolators increases the 3.4 Hz frequency response, but decreases the 10 Hz response by about an order of magnitude. At 10.5 Hz, the effect of the longitudinal isolators is more pronounced, where a frequency response is completely

eliminated. Above 10.5 Hz, the two spectra levels appear about the same. For probe 6, (vertical direction) the effects of longitudinal isolators are more pronounced, for not only is the 3.4 Hz energy level increased by almost an order of magnitude but also between 10 Hz and 40 Hz, substantial increases occur. In fact, without the isolators the 10 Hz frequency peak level is essentially the same as when everything was off (see figure 9) which was at the 10^{-8} power level. For probe 6, these results show that in the vertical direction, the longitudinal isolator appears to increase the response in the 1 to 40 Hz frequency range. For probe 5, lateral direction, the results show that the longitudinal isolators are not as effective for they increased the 3.4 Hz resonance, however, between 5 and 10.5 Hz, the isolators decrease the response.

Amplitude Analysis. - Figure 12 shows the rms values in mils-inches for all probes as calculated for each 10 sec. run obtained with both the compressor and vacuum pumps operating and for the various configuration runs with and without the longitudinal isolators.

The TDL (dotted lines) appears to respond somewhat independent to the response of the Cold Tip; however, not in frequency content as shown in the previous section. For instance, the Cold Tip response was least during the test using the spherical isolators, however, the TDL response does not follow. In fact, the TDL lateral response was greater during this configuration when the spherical isolators were used. Inconsistencies of this order, plagued the results of this investigation.

Figure 12 also shows that the response of the TDL was less than the response of the Cold Tip by an order of magnitude, particularly when the braided thermal strap was used where it was less by a greater than an order of magnitude.

Similarly, plots showing maximum deflection measured peak to peak in mils-inches are presented in figure 13. For the first three configurations without the longitudinal isolators, the Cold Tip responds between .0009652 to .004572 cm (.38 to 1.8 mils-inches). Correspondingly, the TDL responds between .00001778 to .00013716 cm (.007 to .054 mils-inches), peak to peak. For the braided strap, without longitudinal isolator, the maximum response of the TDL is .00009398 cm (.037 mils-inches or .000037 inches), peak to peak. This reduction of deflection which is less than 1 micron double amplitude, (the criteria established for an acceptable response of the TDL) is due mainly to the redesign of the LHS Model 21 Cooler assembly, where the TDL is appropriately isolated from the working part of the cooler and is ready for future operation.

As mentioned above, the response of the TDL appears to be less when the longitudinal isolators were not used. In fact, in each condition except one, comparing the values for probes 5 and 6 with and without the isolators in figure 13, less deflection was measured without the isolators. The one condition in which the deflection was different occurs on probe 6 with the 1.905 cm (3/4 inch) isolators, however so small. The Cold Tip does not respond similarly though, for the differences are more random in nature.

Another form of the amplitude display is shown in figure 14 where deflection is given in percent of the time of occurrence. These data were digitized at 500 samples per second resulting into 5000 samples for each 10 second run. The percent of counts displayed on the ordinated scale of figure 14 is the percentage of digitized values for a given deflection to the total count of 5000 points. The sum of the percentages as measured for each deflection interval per run, therefore, results into 100% of the counts or time. These plots also show the effect of the longitudinal isolators on the response of the TDL. As mentioned before, the longitudinal isolators do not benefit the LHS system.

It appears that the Reaction Bellows are sufficient to carry the compressor load in the longitudinal direction without the two additional isolators. The dotted envelope shown in figure 14 represents the response of the probes 5 and 6 without the longitudinal isolators. By visual observation and comparison of figures 14a, b, and c, you can readily determine the most effective isolation by the narrowness of the histogram. The greater the width, the greater is the response.

CONCLUDING REMARKS

On the basis of the data obtained on the newly designed LHS, a number of significant observations can be made:

1. The response of the TDL was less without the longitudinal isolators than with the isolators.

2. The response of the TDL was approximately one order of magnitude less than that of the Cold Tip.

3. The braided thermal strap together with the one-inch isolator provided for the best overall response of the TDL compared to the other configurations tested.

4. The compressor operation greatly influenced the responses of the TDL, for when the compressor was off, the TDL responded at the noise level.

5. The predominant frequency of the operating system is 3.4 Hz, the compressor frequency.

6. The redesign of the LHS system provided for adequate isolation of the TDL for future operation.

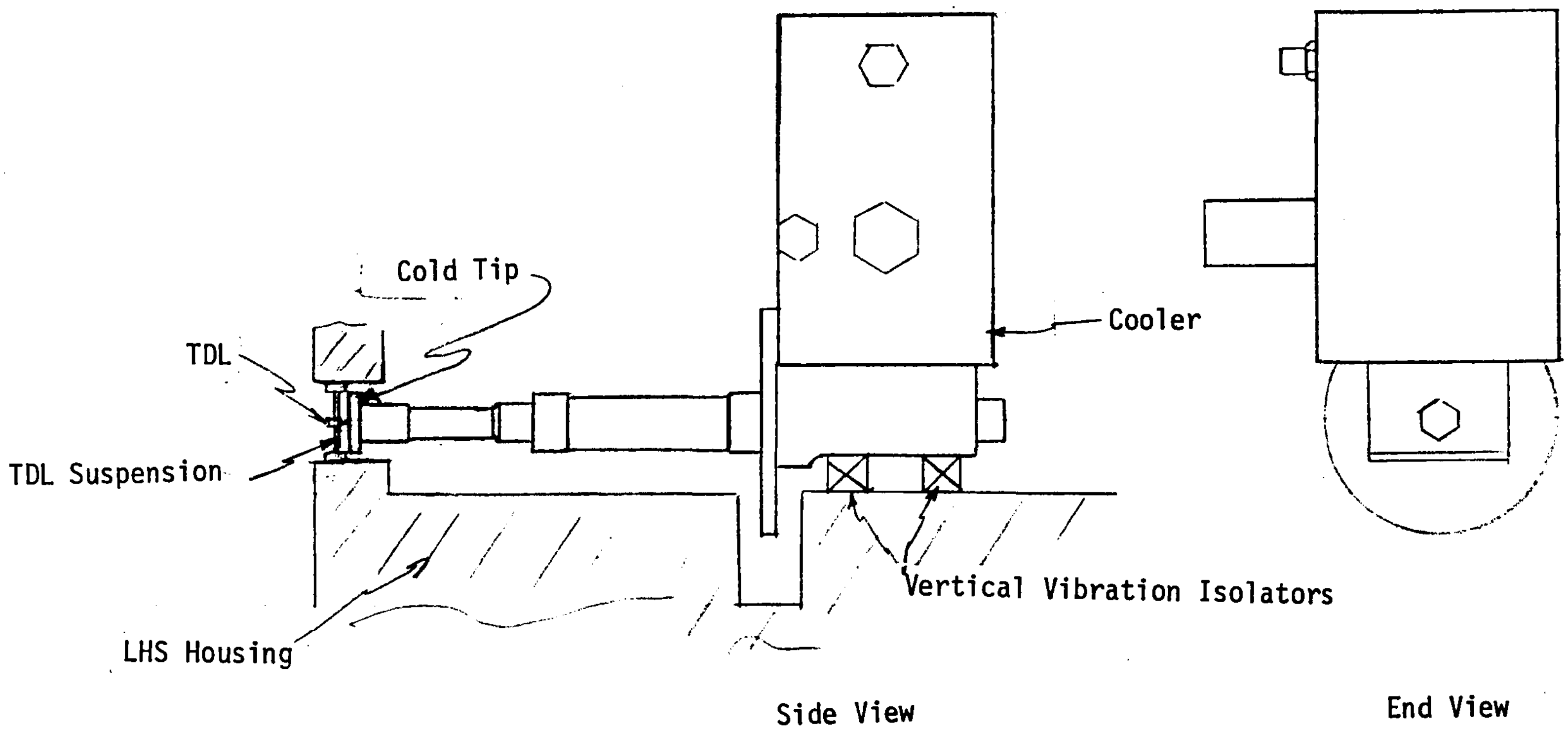


Figure 1. Original design of LHS system.

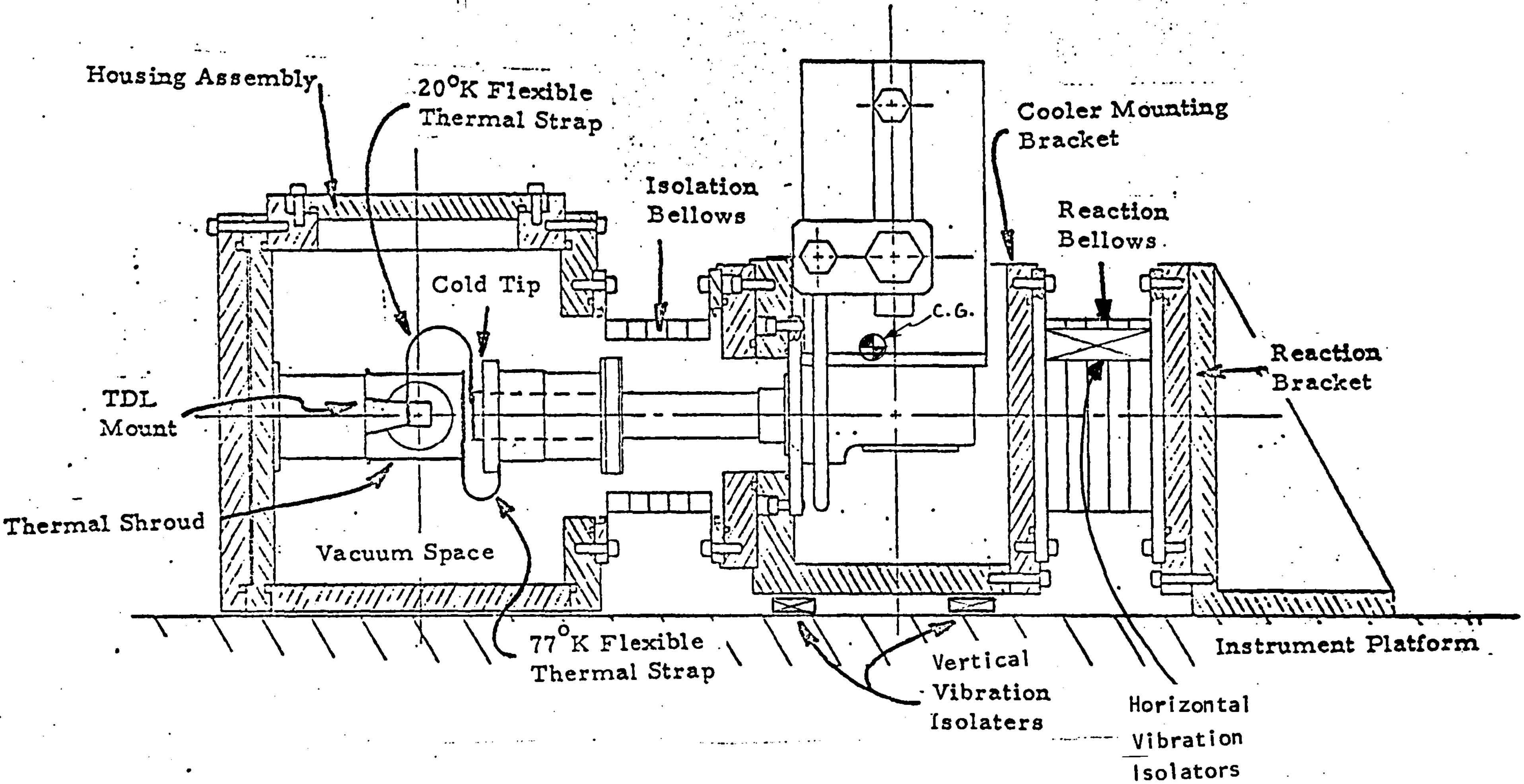


Figure 2. LHS Cooler Test Bed Hardware Assembly (Side View)

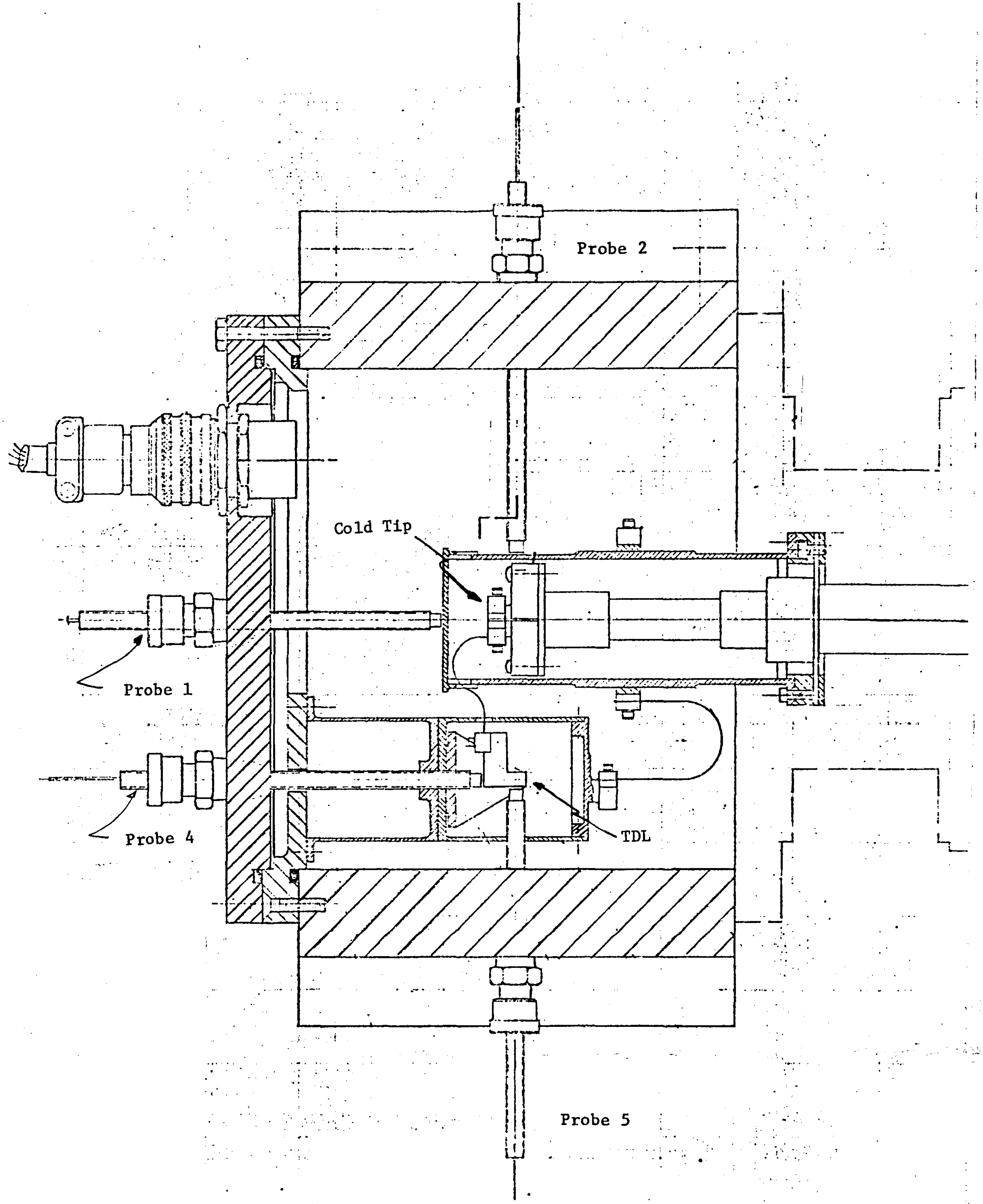


Figure 3 - Probe Locations (Plan View)

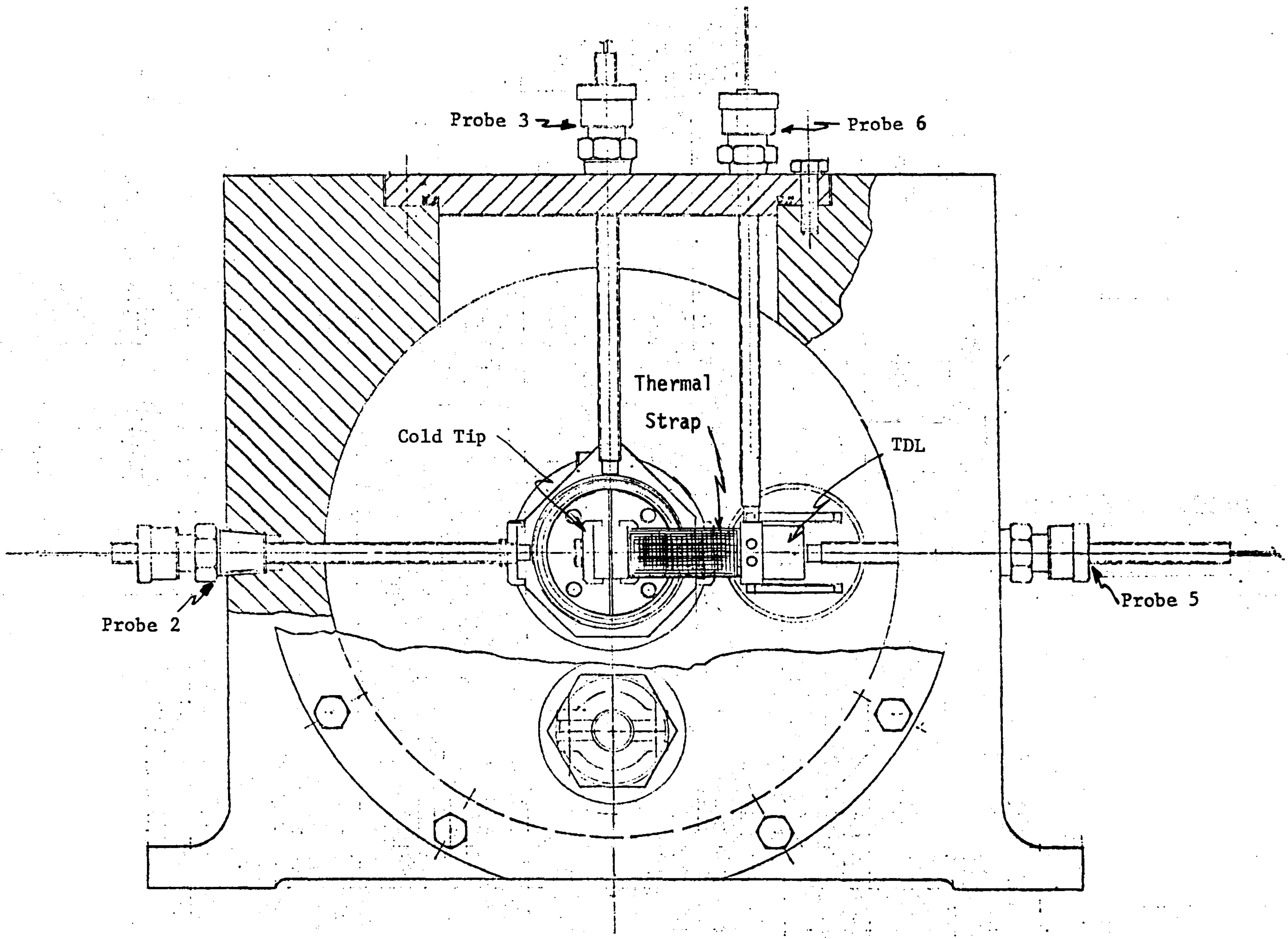


Figure 4 - Probe Locations (End View)

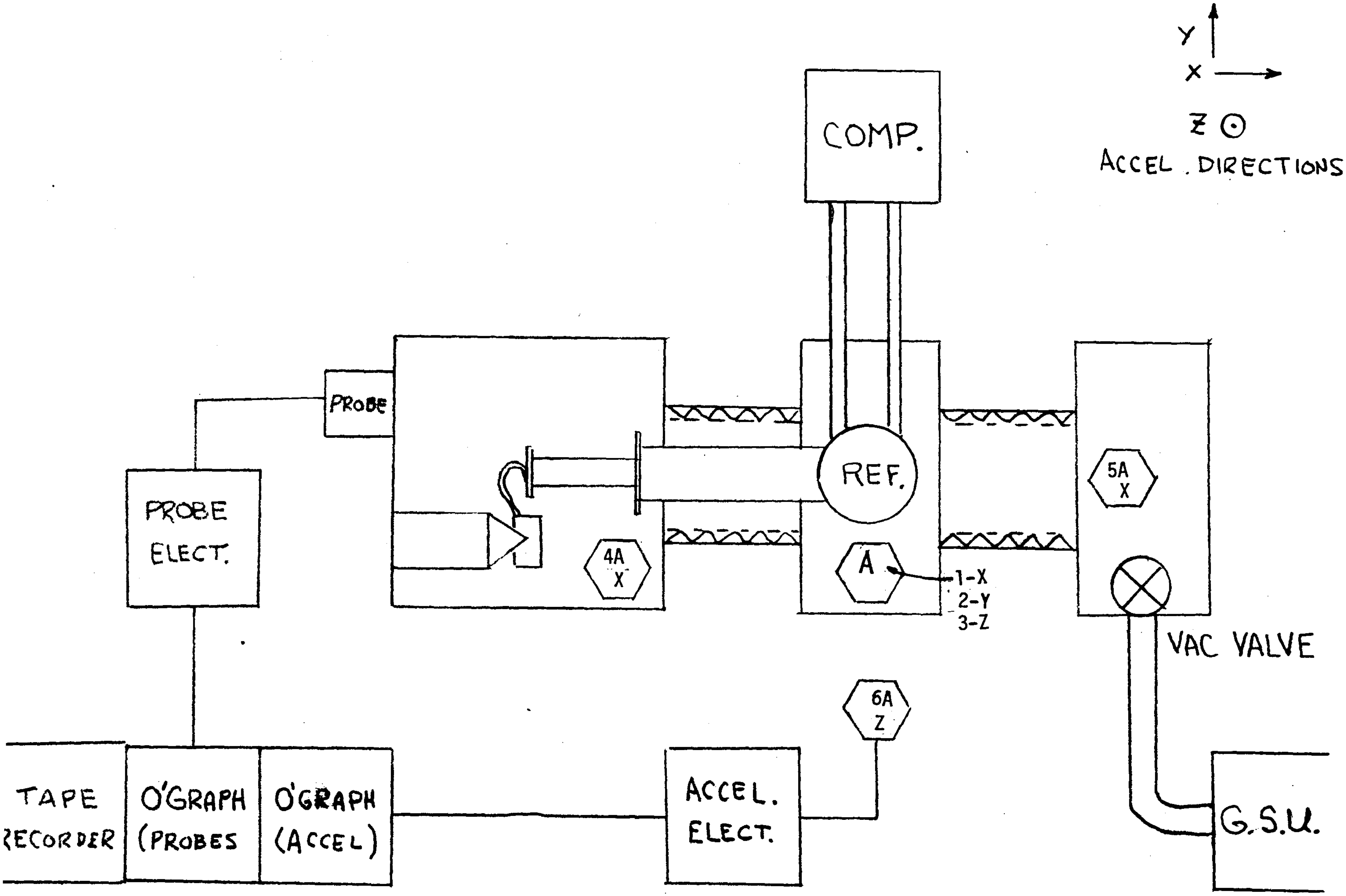


Figure 5. - Test Setup Schematic and Accelerometer Location.

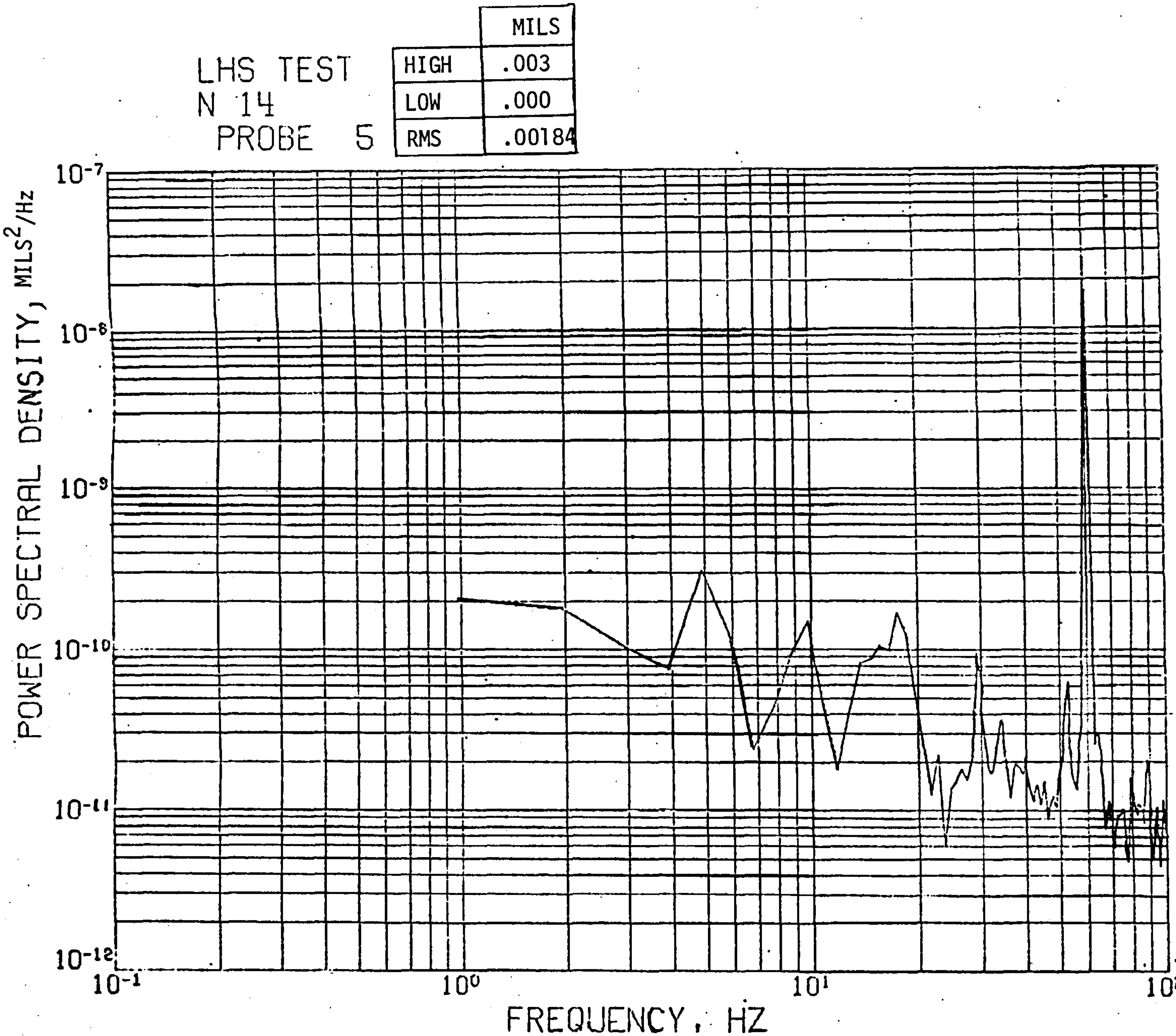


Figure 6. PSD for probe 5 with everything off.

1 cm = 393.7 mils

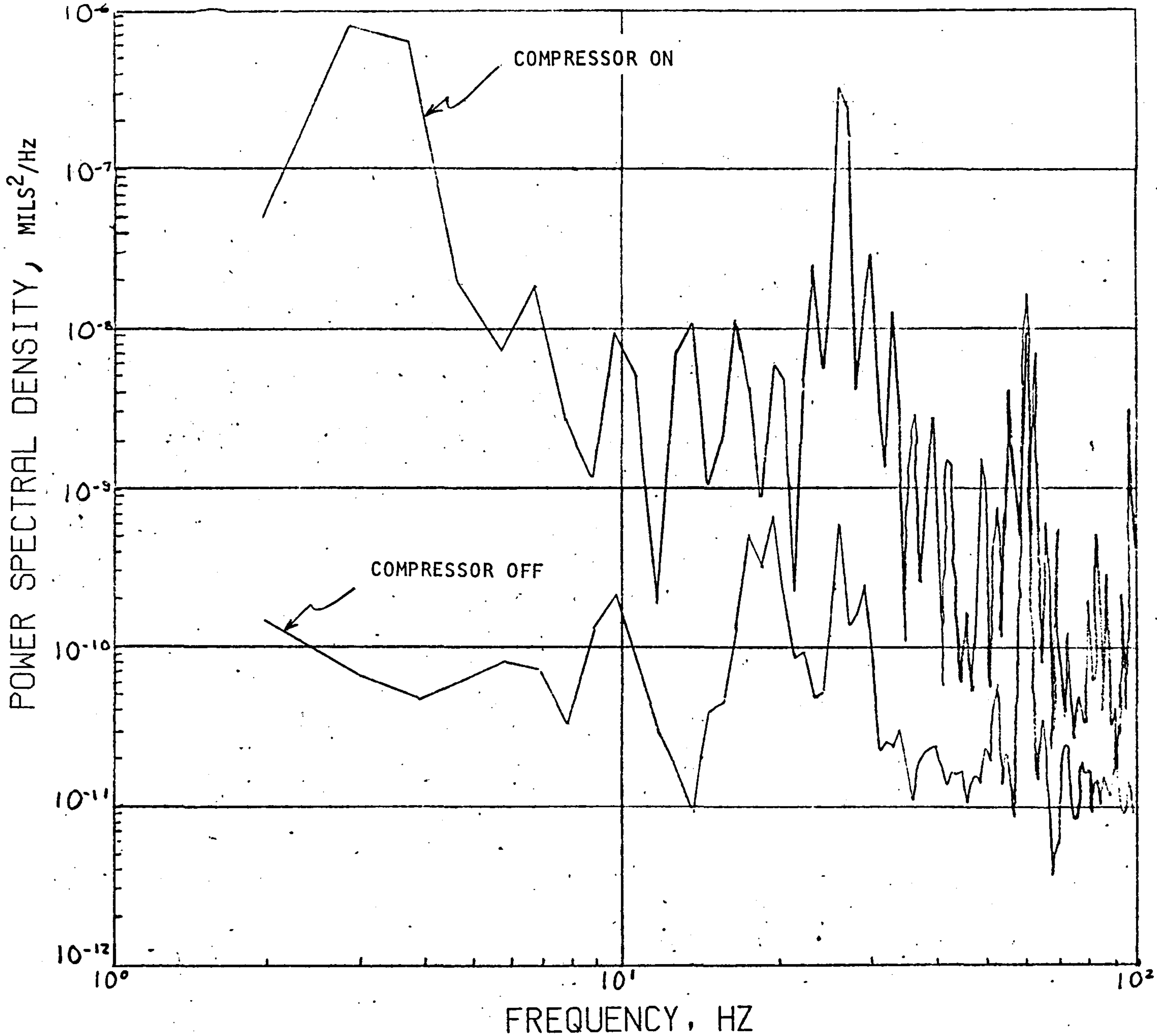


Figure 7. Comparison of PSD with and without compressor operation, probe #5, lateral direction.

1 cm = 393.7 mils

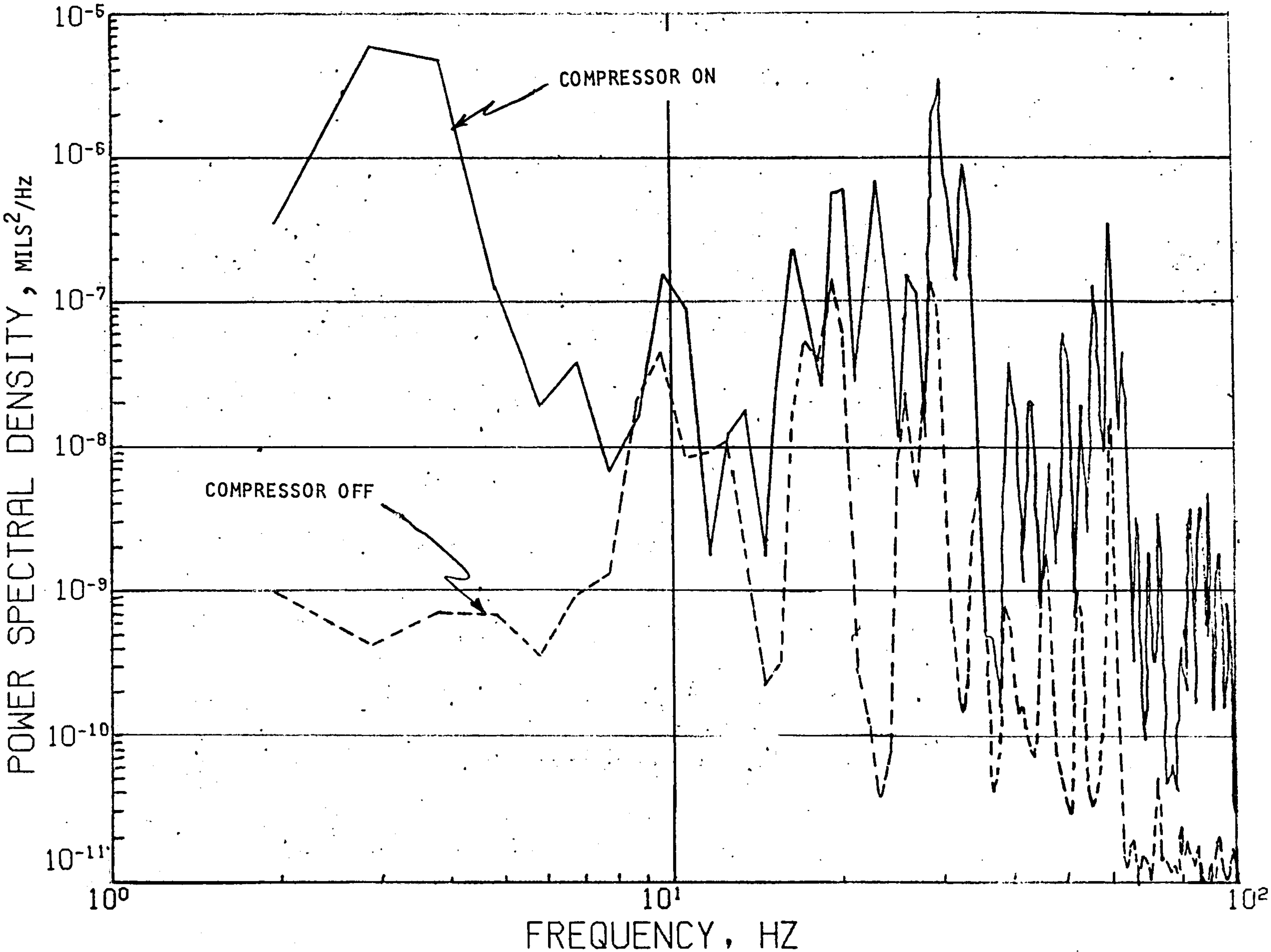


Figure 8. - Comparison of PSD with and without Compressor Operation, Probe #6, Vertical Direction.
1 cm = 393.7 mils

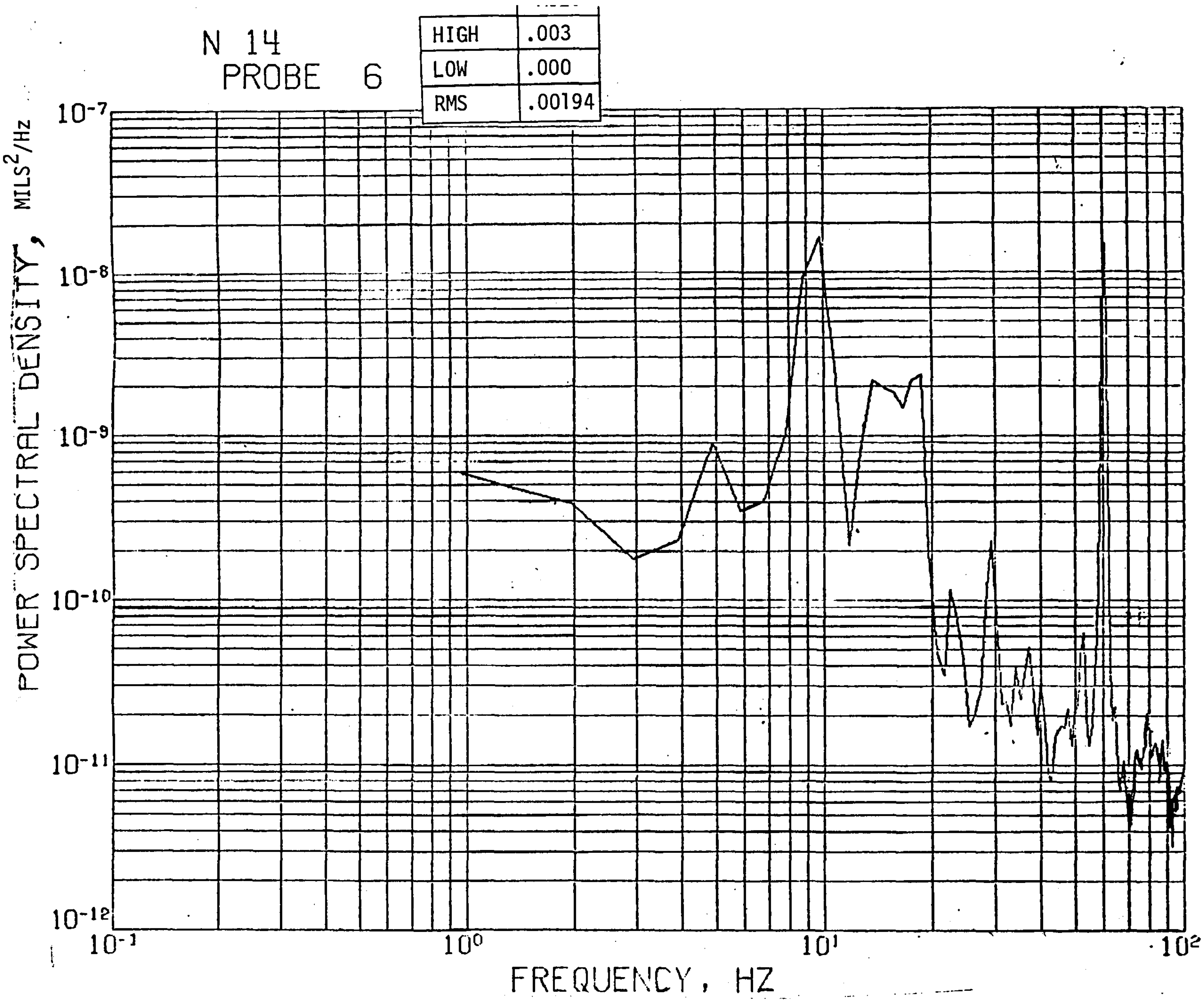


Figure 9. - PSD Plot for Probe 6 with Everything Off.

1 cm = 393.7 mils

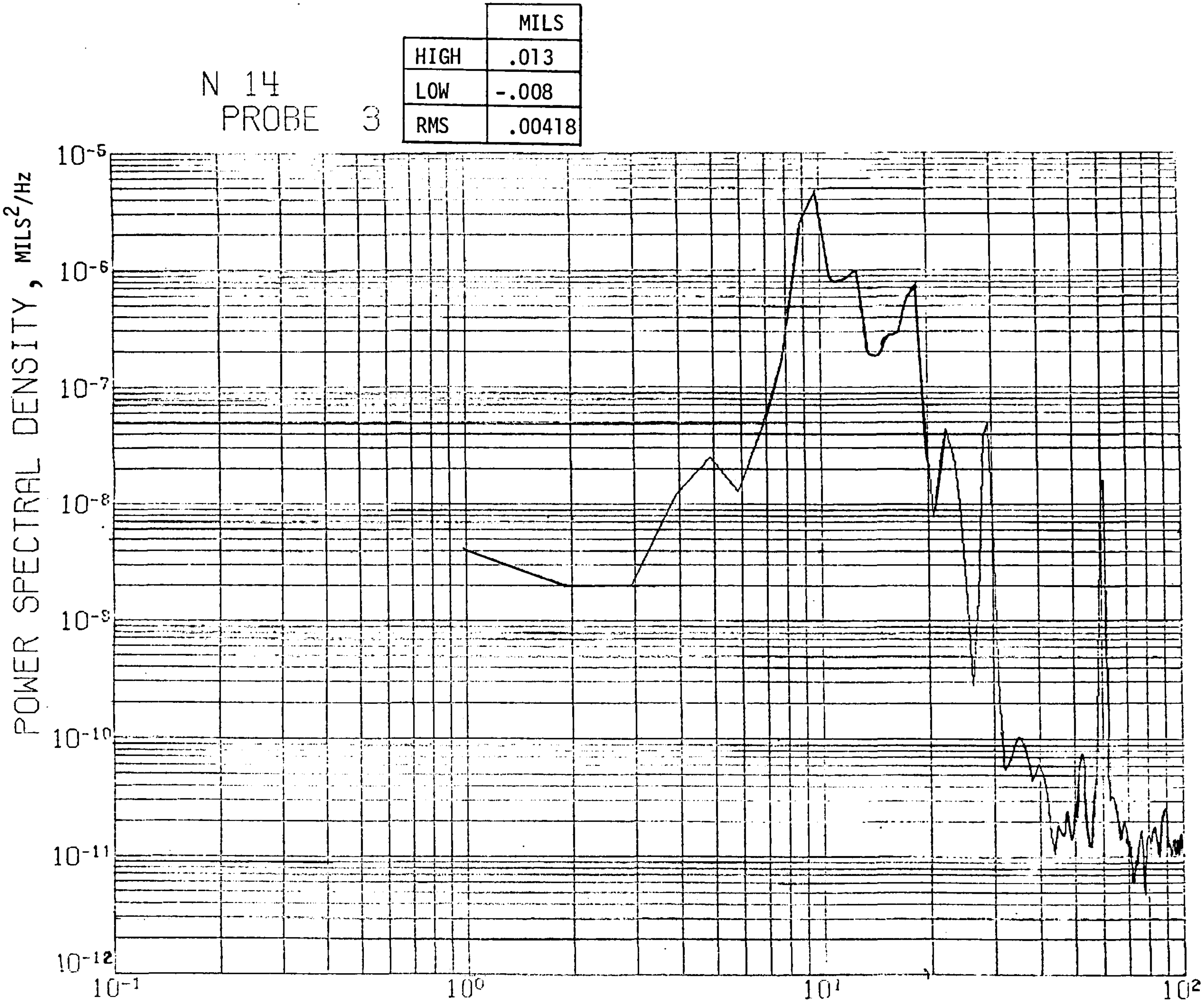


Figure 10. PSD Plot for Probe 3, Vertical Direction of Cold Tip, Everything Off Condition.

1 cm = 393.7 mils

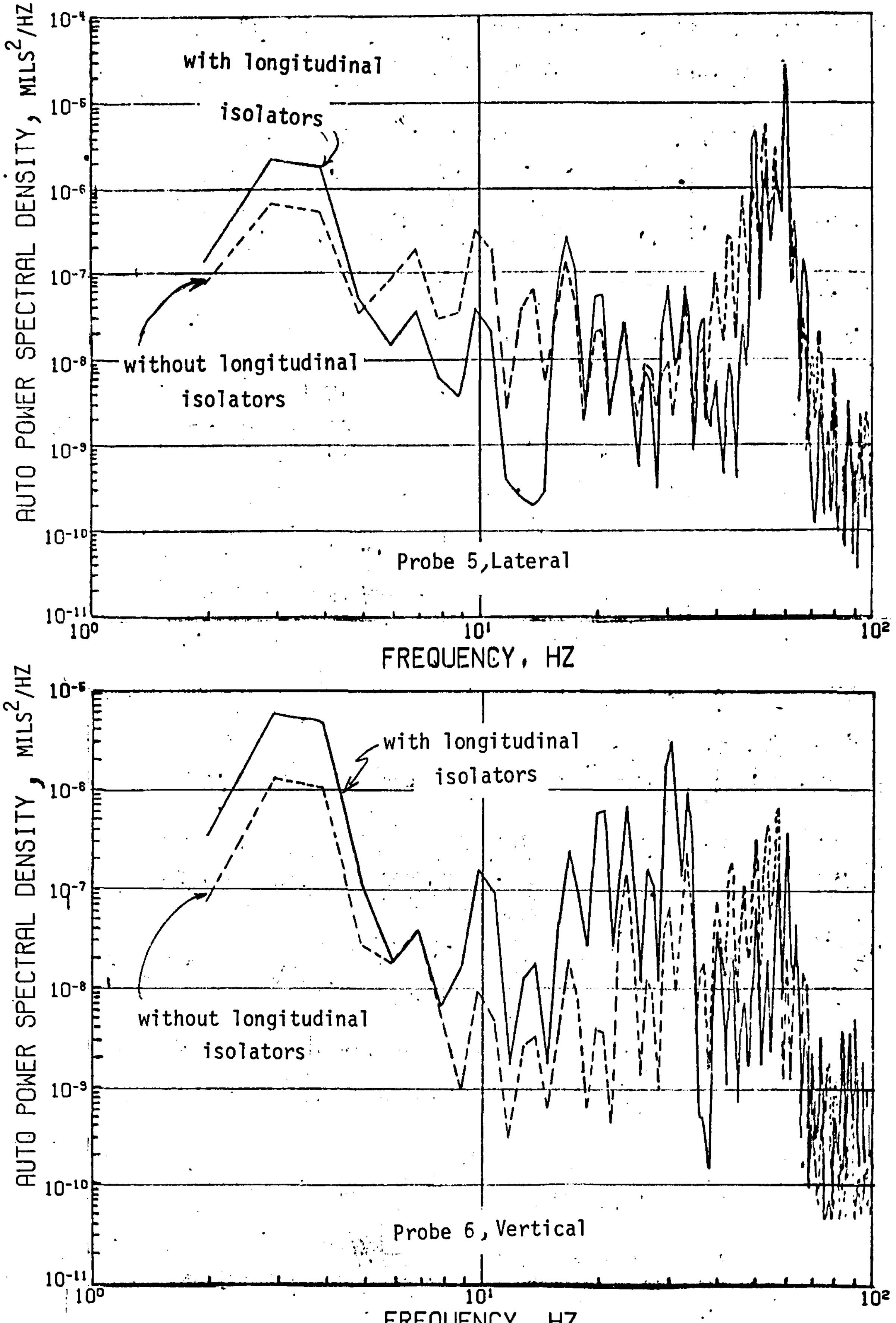


Figure 11. Comparison of PSD plots with and without longitudinal isolators; Probes 5 and 6; Compressor and vacuum pumps on.

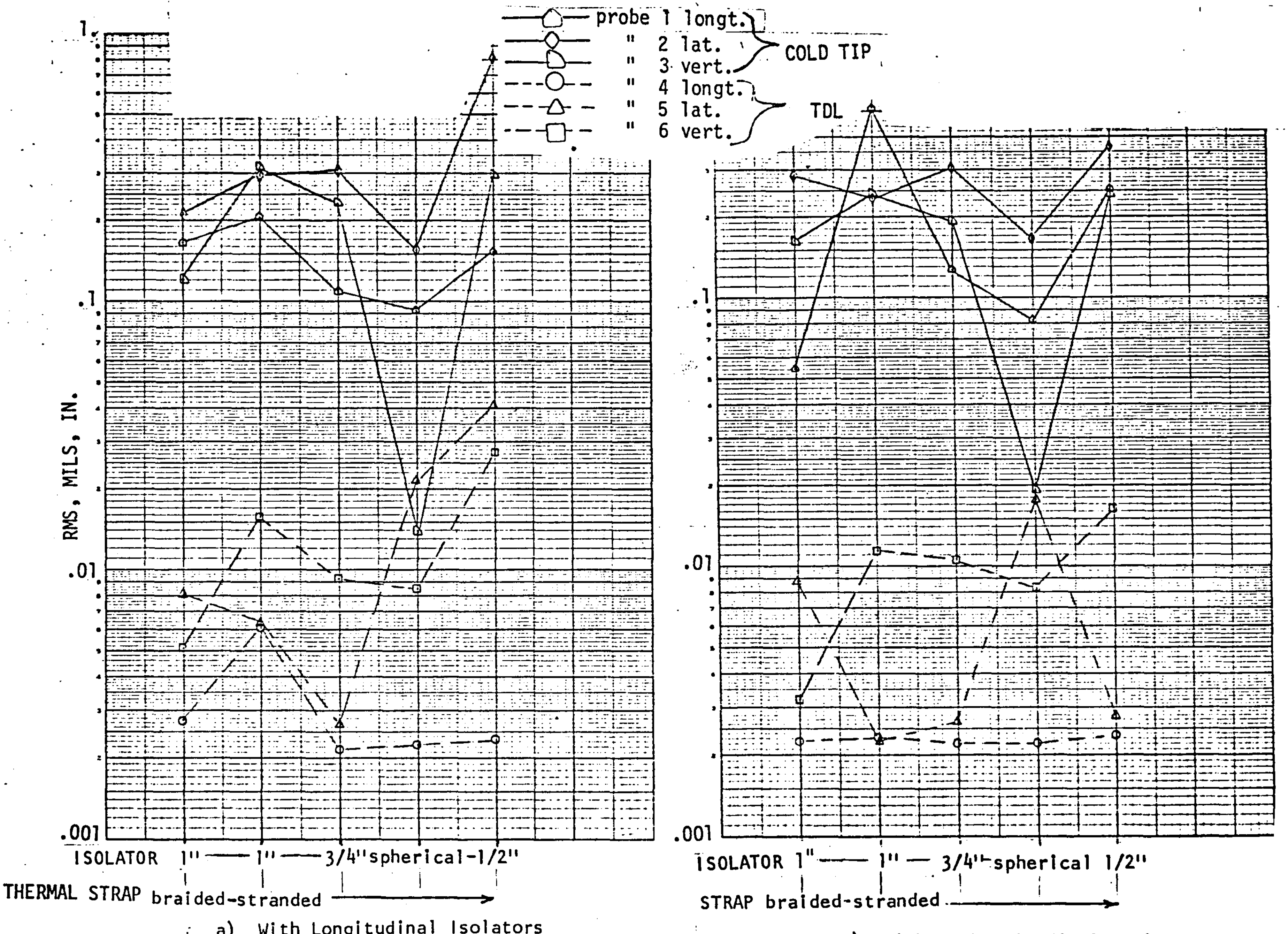
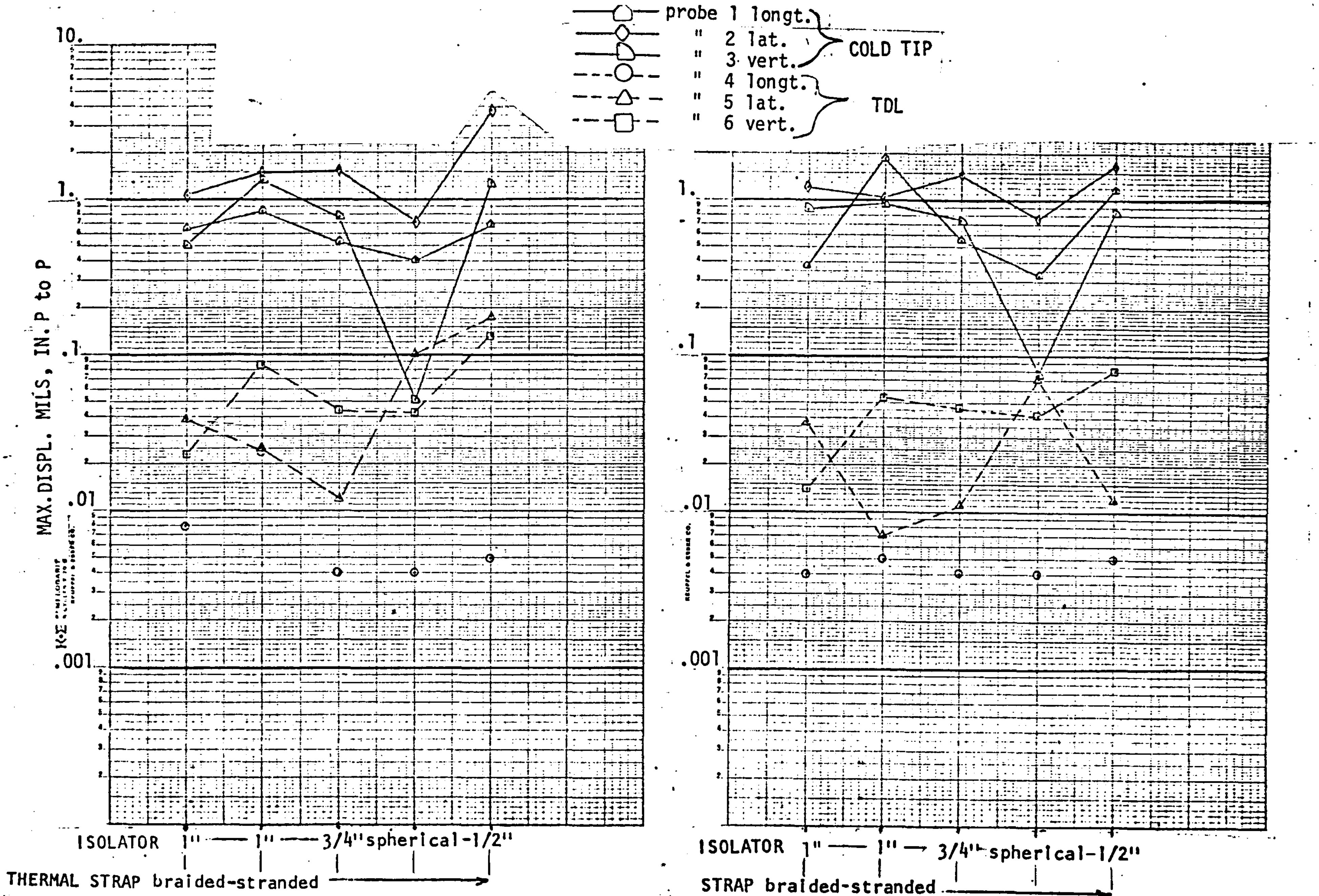


Figure 12. Values of RMS for Each Probe for Various Configurations.

1 cm = 393.7 mils

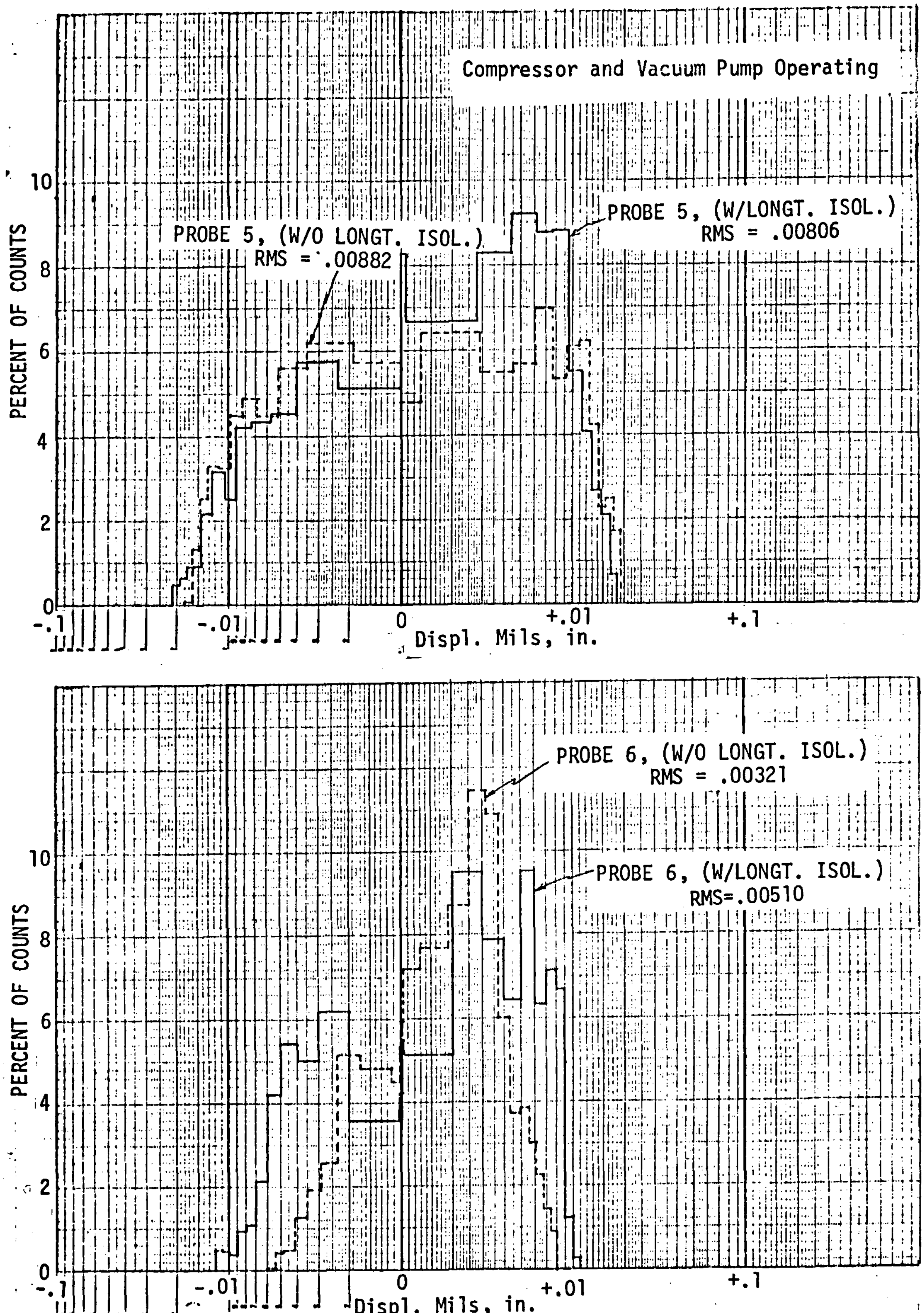


a) With Longitudinal Isolators

b) Without Longitudinal Isolators

Figure 13. - Values of Peak to Peak Displacements for Each Probe for Various Configurations, inches - mils.

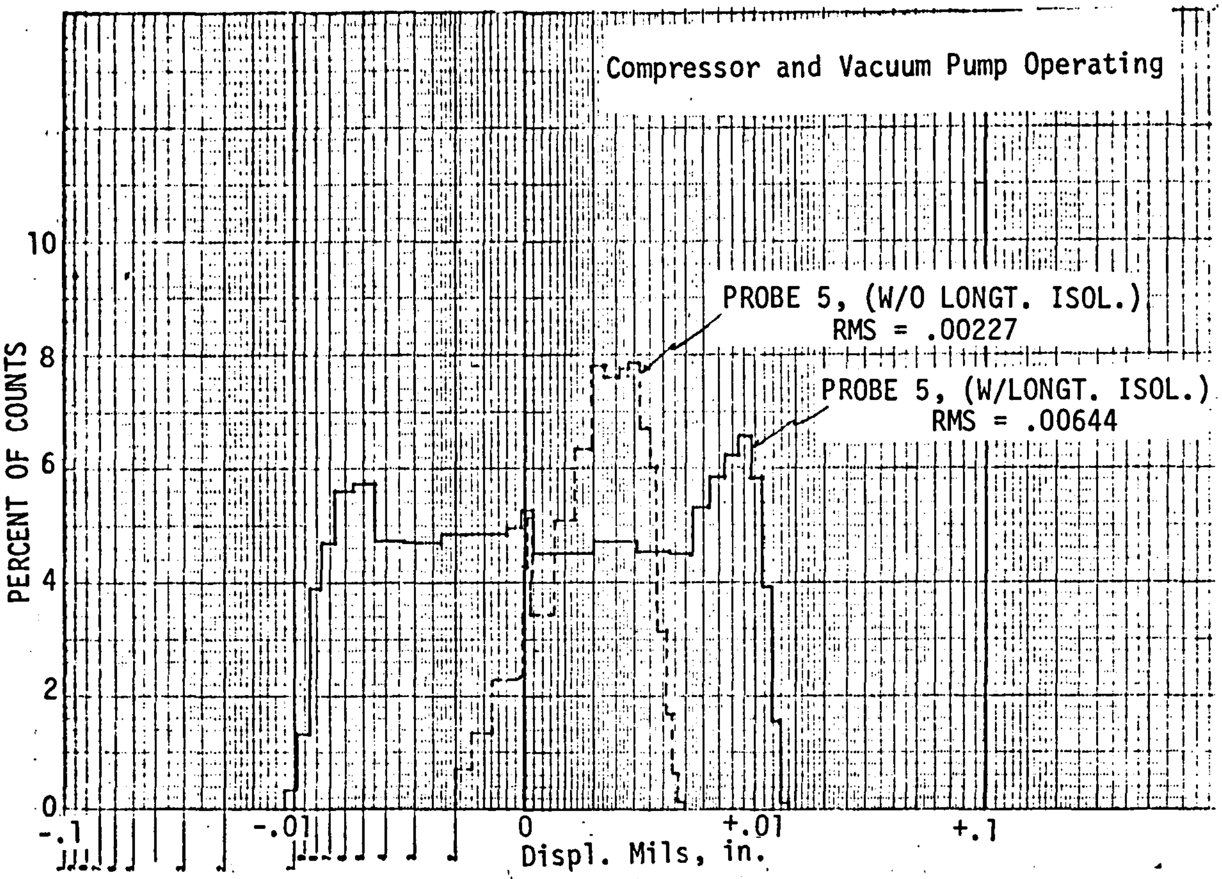
1 cm = 393.7 mils

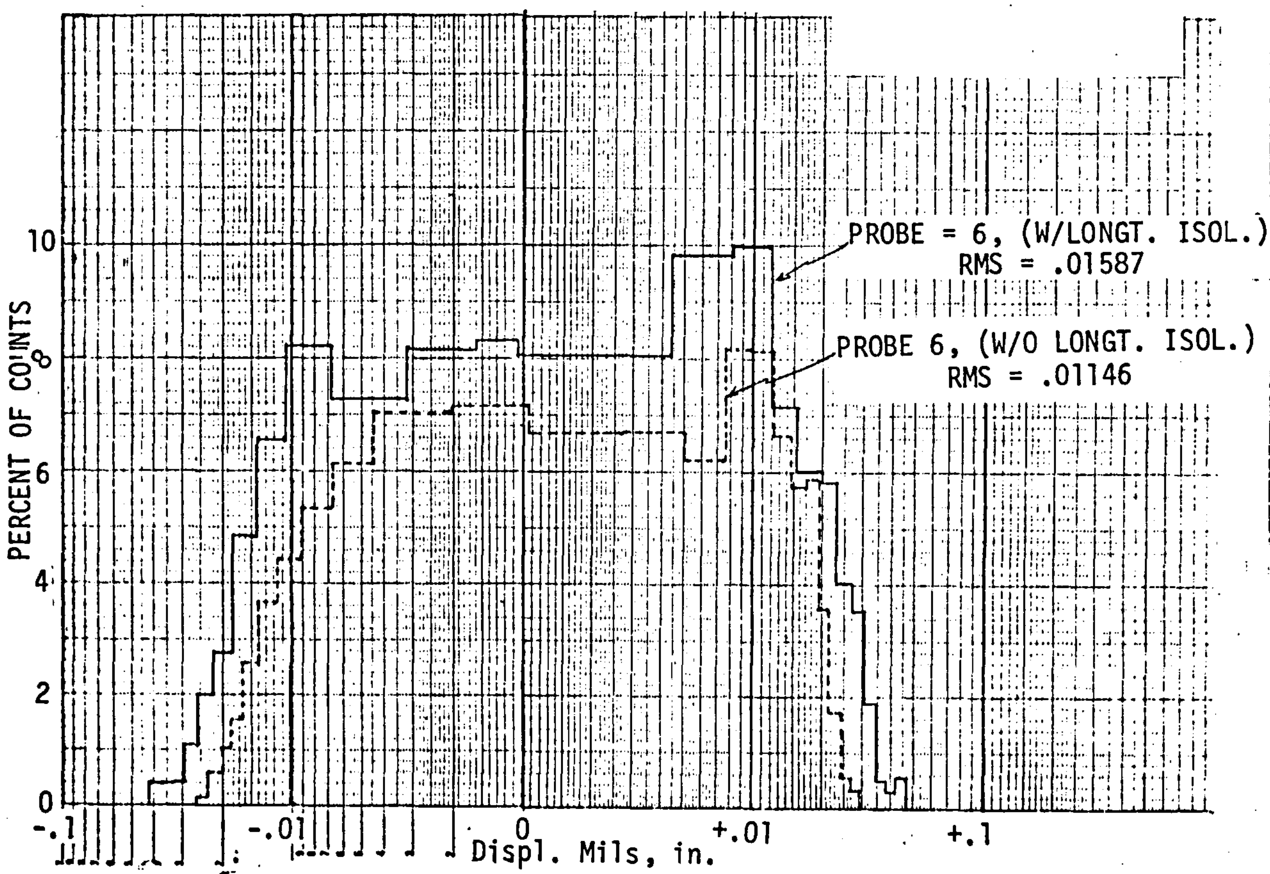


a) 1" Isolators; Braided Thermal Strap.

Figure 14. Deflection Measured as Function of Percent of Time for Probes 5 and 6 During the First Three Configurations With and Without the Longitudinal Isolators.

1 cm = 393.7 mils

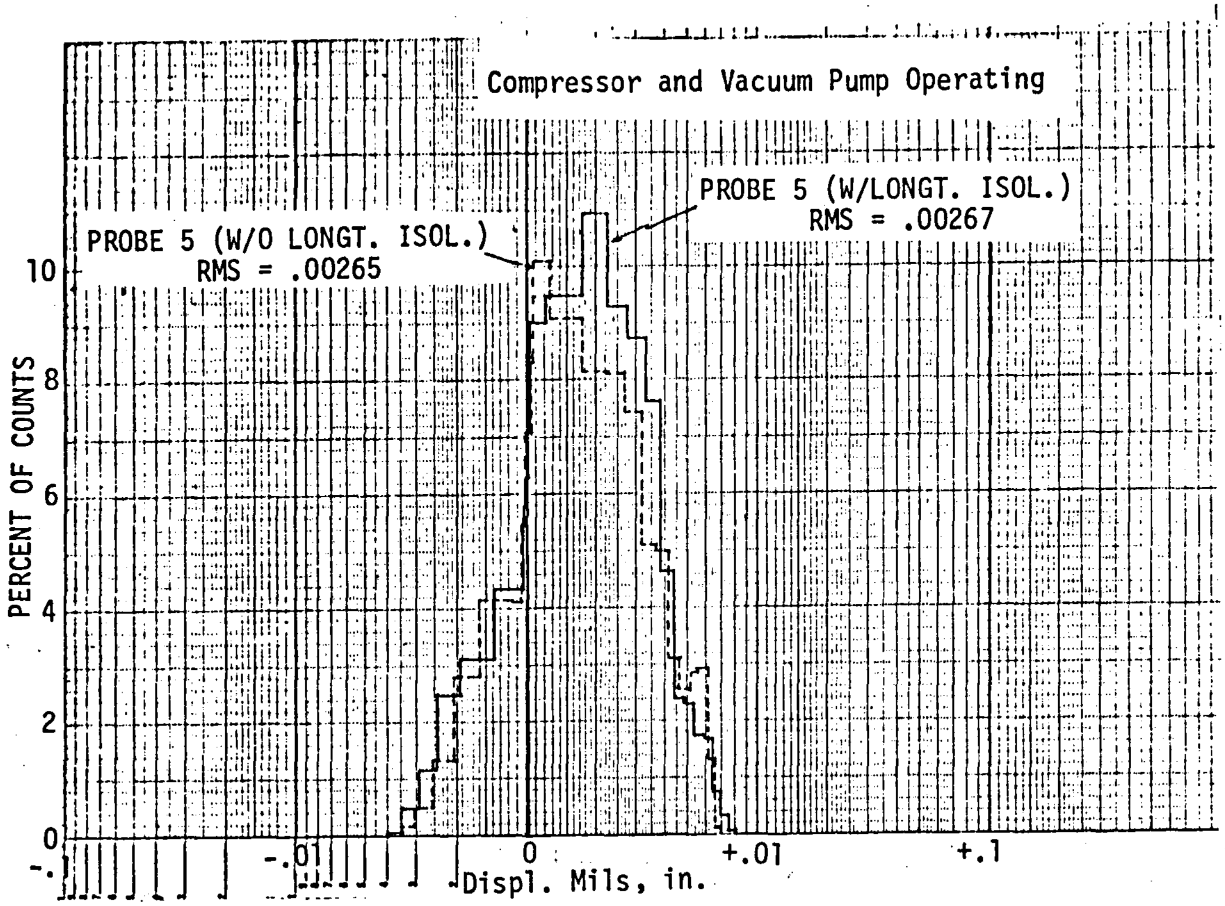


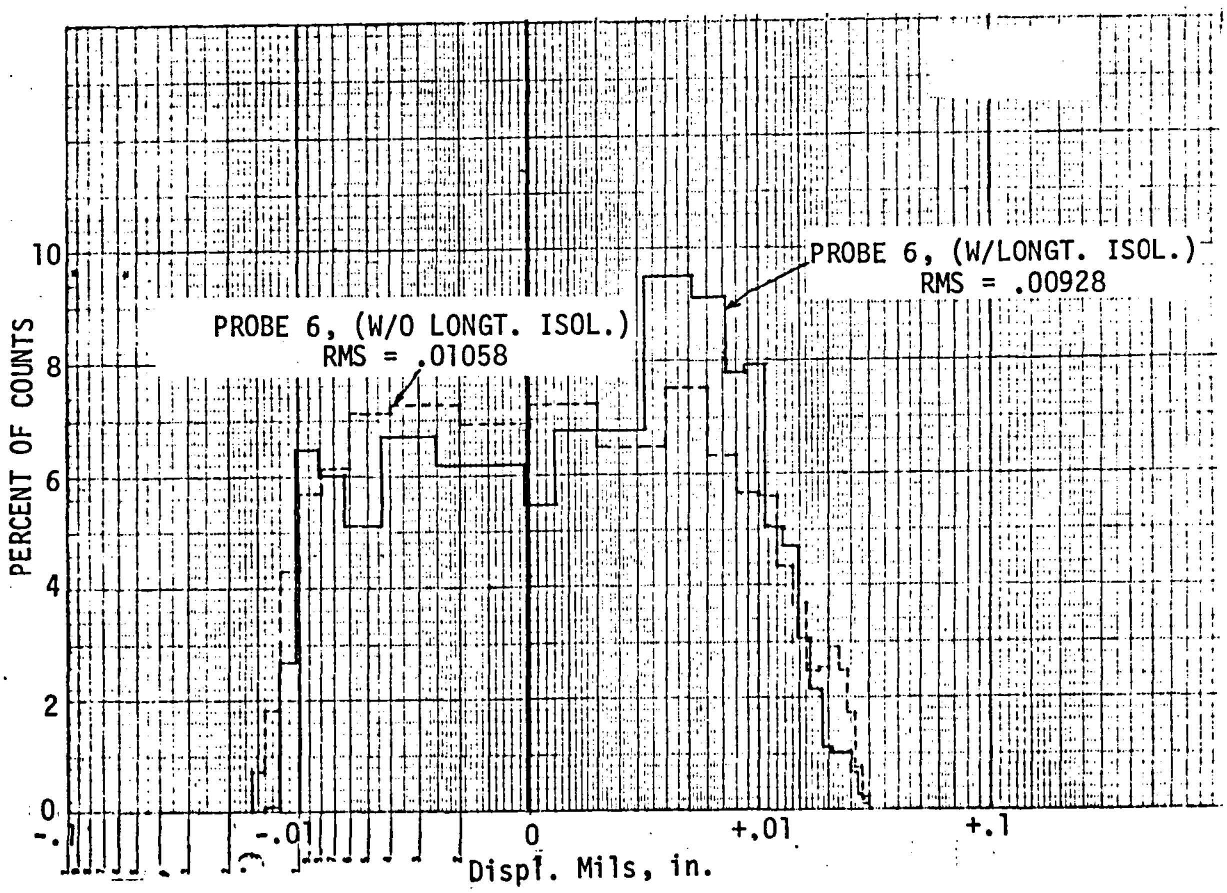


b) 1" Isolators; Stranded Thermal Strap.

Figure 14. Continued.

1 cm = 393.7 mils





c) 3/4" Isolators; Stranded Thermal Strap.

Figure 14. Concluded.

1 cm = 393.7 mils

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15. Supplementary Notes

16. Abstract

The Langley Research Center has recently redesigned the cooler test bed hardware for the G-M Model 21 refrigerator for the purpose of isolating the Tunable Diode Laser (TDL) from the Cold Tip in a Laser Heterodyne Spectrometer (LHS) system. Deflection in the lateral and vertical directions were managed on the Cold Tip and on the TDL. Measurements were analyzed over the frequency range of 0-100 Hz. The results show that the TDL responds approximately one order of magnitude less than that of the Cold Tip. The redesign of the LHS system provided for adequately isolating the TDL for future operation.

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